Joseph Raymond Wilson

AMOUNT AND DISTRIBUTION OF WATER MASSES IN
FEBRUARY AND MARCH, 1962
IN THE GULF OF MEXICO.

AMOUNT AND DISTRIBUTION OF WATER MASSES

IN FEBRUARY AND MARCH 1962 IN THE GULF OF MEXICO

A Thesis

by

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Lieutenant, United States Navy

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CHAPTER I

INTRODUCTION

The primary purpose of this study is to estimate quantitatively for the Gulf of Mexico the amounts of water of different classes according to temperature - salinity characteristics.

The secondary objective of this thesis is to analyze, explain and interpret the results obtained being especially interested in water mass or water type modification in the Gulf of Mexico. Comparisons are made of the water in the eastern and western Gulf and between the Gulf of Mexico and the Caribbean Sea. This report sets forth a composite picture of the distribution of water types in the Gulf of Mexico with the object of noting the water types that are especially germane to the region.

In this study the term water mass is used as is customary to describe water having a distinctive T-S curve, while the term water class is used to mean water having only specified ranges of temperature and salinity. The use of the term temperature will imply potential temperature unless otherwise stated.

As more and more oceanographic data from the Gulf of Mexico is collected and analyzed, it becomes more apparent that the Gulf is a very dynamic and changeable body of

water. Many studies of the Gulf have resulted in inconclusive results for two reasons: (1) the failure to consider the veracity of the data and (2) the practice of combining the results of too many cruises without taking into account year to year or season to season changes. Often in trying to achieve broad data coverage from a sparsely sampled region, the above shortcomings were overlooked. Keeping the above in mind, all discussion here concerns conditions in the Gulf of Mexico only during February and March, 1962. All comparisons to the Caribbean Sea are based on the results of Sturges (1965). It is especially fortunate that Sturges' study is also based on data collected in the winter season (February and March 1958 and December 1954).

An attempt will be made to explain the formation of Gulf water (Figure 10) and concomitantly to show the importance of the Campeche Bank region to water mass formation and modification in the Gulf of Mexico.

CHAPTER II

LITERATURE REVIEW

One of the early investigators of the water masses in the Gulf of Mexico was Wennekens (1959). He defined three water masses in the Gulf: Yucatan, Continental Edge and Western Gulf of Mexico water. Of these three water masses the Yucatan water most closely resembled the waters of the Caribbean Sea.

Wennekens described the geographic extent of the Yucatan water as having its average northern boundary at a latitude slightly south of Tampa and the western boundary marked by a line drawn along the one hundred fathom contour along the eastern Campeche Bank to the Mississippi Delta. The eastern boundary of the Yucatan water is situated slightly to the east of the one thousand fathom contour of the Florida shelf. The distinguishing feature of the Yucatan water is a salinity maximum greater than 36.6 per mil in the temperature range 20°C to 23°C.

The Continental Edge water was defined to include waters located between the northern and eastern edge of the Yucatan water and the coast. The predominant feature of the Edge water is the marked reduction of the strength of the salinity maximum. Wennekens postulates that the two main processes which are involved in the formation of new

water masses in the Gulf of Mexico are evaporation and cooling.

The Western Gulf of Mexico water was characterized by the absence of a strong salinity maximum below 90 meters. Wennekens saw the Continental Edge water as having intermediate characteristics between the Yucatan and Western Gulf water. It is interesting to note that there are practically no differences in the form of the T-S curves of water masses throughout the Gulf of Mexico at temperatures below 17°C.

The primary source of the water of the Gulf of Mexico is the northward flow of Caribbean water through the Yucatan Strait. An accurate sill depth in the Yucatan Channel has not yet been determined but McLellan and Nowlin (1963) estimated, on the basis of potential temperature, that it is less than 1900 meters.

The water masses of the Gulf may also be explained in relation to what is now called the loop current in the east Gulf. The waters located near the center of the loop current closely resemble the Caribbean water flowing through the Yucatan Channel. Nowlin and McLellan (1967) note that this center loop water T-S curve is characterized by a salinity maximum greater than 36.7 per mil between 20°C and 24°C.

In the northeast Gulf Gaul (1966) showed that in a series of T-S relations from stations progressing northward from the center of the loop, the salinity maximum decreased. Gaul also found high salinities (36.60 per mil and 36.64 per mil) near the northeast Gulf boundary (his stations A1 and A2) which strongly suggested that on occasion the Yucatan Channel flow penetrated this far into the Gulf.

Leipper (1967) has shown that the location and extent of the loop current has a dominant influence on the amount and distribution of water masses in the east Gulf.

Ichiye (1962) analyzed the water mass distribution in the Gulf of Mexico from 1951 to 1955 using data collected by Texas A&M personnel on the Alaska of the U.S. Fish and Wildlife Service and the Jakulla of Texas A&M.

Ichiye (1962) included in his study a section on the statistical characteristics of Gulf water using the method initiated by Cochrane (1958), Pollak (1958) and Montgomery (1958). Ichiye concluded that because of the great quantity and uniformity of the water in the Gulf of Mexico having a temperature below 8°C, the difference between the western and eastern parts was not as conspicuous as expected. Ichiye's data included few samples below 1000 meters.

Sturges (1965) has completed a detailed examination of the water characteristics of the Caribbean Sea using

the method of Cochrane, Pollak and Montgomery. The results obtained in this present study will be compared with the findings of Sturges (1965) and will offer an insight into the formation of water classes characteristic to the Gulf.

CHAPTER III

PROCEDURE

The data used for this study were collected on cruise 62-H-3 aboard the R.V. Hidalgo during the period from February 12 to March 31, 1962. The chief scientist was Dr. Hugh J. McLellan. This cruise included 126 hydrographic stations covering the entire Gulf of Mexico as shown in Figure 1. Cruise 62-H-3 represents the most comprehensive quasi-synoptic survey of this total area that has been obtained to date. Sampling was accomplished using Nansen bottles and paired reversing thermometers. Salinities were obtained by using a shipboard conductive salinometer built by the University of Washington. This cruise was also very advantageous for the present study since many deep samples (depths greater than 1500 meters) were obtained.

The cruise data report was made by McLellan and Nowlin (1962). The deep waters of the Gulf of Mexico were studied by McLellan and Nowlin (1963) using this data. The shallower water layers were analyzed by Nowlin and McLellan (1967).

In this thesis the method of Cochrane, Pollak and Montgomery will be used with slight modification to estimate the volumes of the different water classes in the Gulf.

The Gulf was divided into units of one degree squares of longitude and latitude. Then a station or group of stations were chosen which the author believed best described the water in a given one degree square. The procedure is described in detail in Appendix A.

CHAPTER IV

DISCUSSION OF RESULTS

Discussion of Figures

Before studying Figures 2 through 8 the reader should have an idea of the general form of most of the T-S curves of the Gulf (Figures 9 and 10). Stations used in Figures 9 and 10 were chosen to show a broad geographic sample. Often a large quantity of water in a given temperature - salinity classification can be represented by a fraction of the major classification area (2°C and 0.2 per mil).

For each T-S volume presentation (Figures 2-8) numbers at the extreme right margin are salinity classification totals and numbers along the bottom margin are potential temperature sums. Potential specific volume anomoly sums are not included mainly in the interest of providing a clearer presentation.

In Figures 6 and 7 only water above 16°C is considered. This selection was made to include only the upper waters that come under seasonal influence and are therefore subject to great changes. Since the gradients are large and since strong currents and convective influences are present in the upper layers of the Gulf, mixing processes are more noticeable here. It is therefore deemed appropriate to exclude the large volume of more stagnent water

below 16°C in some presentations.

In the coarse scale presentation (2°C x 0.2 per mil) for the entire Gulf (Figure 2), the mode classification dominates the distribution. The mode occurs in the water class 4°C - 5.99°C, 34.8 - 34.99 per mil and represents over sixty per cent of the water found in the Gulf of Mexico. The salinity mode occurs between 34.8 - 34.99 per mil representing over seventy per cent of total volume. The potential temperature mode lies between 4°C - 5.99°C, which represents over sixty per cent of the total volume.

It should also be noted that a mode exists for the warmer waters (those above 16°C) in the classification 20°C - 21.99°C, 36.2 - 36.39 per mil (18 per cent of the water warmer than 16°C and 23.4 per cent of the water warmer than 18°C). The secondary mode of the salinity classifications is bounded by 36.2 - 36.39 per mil also.

Figure 3 shows on a fine scale (0.2°C x 0.02 per mil) the large volume of deep water having a temperature below 7°C. This figure includes the region of the salinity minimum associated with the Antarctic Intermediate Water. The feature of Figure 3 that is most noteworthy is the mode occurring in the water type 4.0°C - 4.19°C, 34.960 - 34.979 per mil (45% of the entire Gulf). This strong mode is reasonable when it is considered that the Gulf of Mexico

is in free communication with the Caribbean Sea and Atlantic Ocean only across relatively shallow sills.

Sturges (1965) presents the above water class (4.0°C - 4.19°C, 34.960 - 34.979 per mil) as a strong mode of the Caribbean Sea above 4°C. Since water from the Caribbean Sea forms the major source of water in the Gulf of Mexico, it is not surprising that the Gulf has so much of this water. The frequency of renewal of the deep water of the Gulf of Mexico is presently unknown.

We see in Figure 3 also that the salinity minimum is not a strong feature of the distribution and that it is usually located between 5.6°C and 6.4°C. The salinity minimum degenerates as the flow through the Yucatan Channel penetrates into the Gulf.

The temperature of the salinity minimum compares favorably with Sturges' (1965) results for the Caribbean. The minimum salinity for the Caribbean was in the class 34.70 - 34.719 per mil as contrasted to 34.84 - 34.859 per mil for the Gulf. Wust (1964) has applied the core method in his effort to trace out this minimum salinity associated with the remnant of the Antarctic Intermediate Water in the Caribbean. The salinity value of the minimum increases from east to west in the Caribbean. Wust (1964) indicates that the remnant of Antarctic Intermediate Water in the Gulf of Mexico is less than 5 per cent of its original strength.

Figures 4 and 5 represent the distribution in the eastern and western Gulf, respectively. The mode of the upper water (above 16°C) distribution is located in the same classification on both figures (20°C - 21.99°C, 36.20 - 36.39 per mil). The adjacent temperature classes (18°C - 19.99°C, 22°C - 23.99°C) in the same salinity class (36.2 - 36.39 per mil) show noticeable increases in the western Gulf when compared with the same classes in the east. There is a large decrease in the volume of water having a salinity greater than 36.6 per mil in the western Gulf compared to the eastern.

The water in the western Gulf above 36.6 per mil results from samples taken in station 77 located on the western Campeche Bank. The highest salinity water in the eastern Gulf was sampled within the loop current or near the Yucatan Channel. The high salinity water that entered the Gulf from the Caribbean was located in the depth range 100-200 meters (Nowlin and McLellan, 1967). If one stands with his back to the Yucatan current, the Subtropical Underwater salinity maximum is noticeably deeper on the right than on the left. This maximum is reduced as a result of mixing processes (surface convection or sub-surface uplift).

This study indicates that a large percentage of the high salinity Subtropical Underwater is eventually formed

in the Gulf into water having the following limitations of temperature and salinity: 20°C - 23.99°C and 36.2 - 36.39 per mil. Considering only the water above 18°C, over 38 per cent of the entire Gulf, 42 per cent of the western Gulf and 28 per cent of the eastern Gulf is located in the above temperature and salinity range. Over 23 per cent of the water above 18°C is in the class 20°C - 21.99°C and 36.2 - 36.39 per mil. According to Sturges (1965) no water in the above classification exists in the Caribbean Sea. This water type was a distinctive feature of the water of the Gulf of Mexico in February and March 1962.

It is also noticed that the volume of water having a temperature over 24°C is greater in the eastern Gulf than in the west. This results from the higher temperature Yucatan water which is located only in the east Gulf.

The deep water in Figures 4 and 5 (that below 16°C) is dominated by the classification 4°C - 5.99°C, 34.80 - 34.99 per mil representing 62 per cent of the water in the eastern Gulf and 66 per cent of the water in the western Gulf.

The low salinity water (under 36.0 per mil) in the upper layers of the eastern Gulf was sampled at stations located near the mouth of the Mississippi River and on the Florida shelf. The northern and western shelf areas of

the western Gulf were regions where low salinity water also predominated. The water in the western Gulf with salinities less than 34 per mil was sampled at stations 65 and 119.

The water below 4°C in the eastern Gulf resulted from a sample taken at station 7. Its temperature was 3.99°C or just barely in a separate water class.

Figure 6 shows the change of percentage (west-east Gulf) of water volumes of each class with only the upper water above 16°C considered. Many of the contrasts between the east and west Gulf previously discussed are evident in this figure. The high salinity (greater than 36.4 per mil) water of the eastern Gulf appears to be moderated mostly into water having a salinity between 36.2 - 36.39 per mil.

A similar comparison is presented in Figure 7 between the upper waters (above 16°C) of the Gulf of Mexico and the Caribbean Sea. The Caribbean Sea contains a larger percentage of water above 26°C and above 36.6 per mil salinity. The lower maximum salinities of the Gulf result from moderation of the Subtropical Underwater.

The largest percentage changes appear as gains for the Gulf of Mexico. The coarse scale classes that offer the largest contrast between the Gulf and the Caribbean Sea are 20°C - 23.99°C, 36.20 - 36.39 per mil with the mode class 20°C - 21.99°C, 36.20 - 36.39 per mil.

Figure 8 presents a view of the change of percentage of water of similar classes for the entire water volume of the Gulf and Caribbean. The deep water features that predominate are the degeneration of the salinity minimum associated with Antarctic Intermediate Water and the presence of the large percentage of water having temperatures below 4°C in the Caribbean. The colder water of the Caribbean Sea is associated with the deeper basins in this region.

Water Mass Identification

Presented below are some distinguishing differences between Yucatan water and Gulf water. Yucatan water is defined by the temperature versus salinity and oxygen curves in Figure 9 and was located at stations 14 - 24, 36 - 39, 41, 42, and 54 - 58. The Eastern Gulf Loop current is identified by Yucatan water. The Yucatan water sampled had surface salinities less than 36.2 per mil and surface temperatures greater than 25.5°C.

For reasons discussed below the water properties measured at the point closest to 250 meters appear to be good water mass identification indicators based on data collected on cruise 62-H-3. The average phosphate-phosphorous and oxygen at this level for Yucatan water were 0.63 micro-gram atoms per liter and 3.41 ml/l respectively.

If the oxygen value at station 39 is neglected, Yucatan water oxygen values at the sample closest to 250 meters varied from 3.03 ml/l (station 19) to 3.64 ml/l (station 17). The phosphate-phosphorous range at the same point varied from 0.30 micro-gram atoms/liter (station 24) to 0.77 micro-gram atoms/liter. At the sampling point closest to 250 meters for Yucatan water all temperatures were greater than 15.62°C (station 58), salinities greater than 36.041 per mil (station 58) and sigma-t less than 26.65 g/l (Note Appendix B).

Gulf water is the most abundant water mass in the Gulf of Mexico and is defined by the temperature versus salinity and oxygen curves in Figure 10. The distinguishing feature of the Gulf water T-S curve is the degeneration of the Subtropical Underwater salinity maximum to values usually less than 36.4 per mil.

In contrast to Yucatan water the surface temperature of Gulf water is lower and the surface salinity greater (typically less than 25°C and greater than 36.2 per mil in winter 1962). Exploring the 250 meter properties of Gulf water is noted in Appendix B, one notes temperature less than 15.62°C (except station 4, 5, 25, 60, 70 and 71), oxygen less than 3.03 ml/l and phosphate-phosphorous greater than 0.77 micro-gram atom/liter (except stations 4, 5, 25, 60, 70 and 71). The stations noted in exception

represent water that has intermediate characteristics between Gulf and Yucatan water.

Edge water for this cruise was identified by temperatures less than 22°C and salinities less than 36.0 per mil at the surface. Edge water is most common in areas on or near the shelf and the low salinites often result from coastal drainage into the Gulf.

The northwest corner of Campeche Bank was characterized by water with a temperature greater than 22.8°C and salinities greater than 36.4 per mil (greatest quantities located at stations 8, 9, and 73 - 77). The water so described is west Campeche water and probably results from excessive evaporation. Franceschini (1961) showed that in the Gulf evaporation generally exceeds precipitation. He also noted in exception that during February and March 1959 the western Gulf was characterized by a net addition of fresh surface water. Nowlin and McLellan (1967) suggested that a permanent eddy may exist in Campeche Bay based on low oxygen observations noted in this region. It is therefore suggested that most, if not all, west Campeche water noted on cruise 62-H-3 was formed prior to the winter of 1961-1962. The west Campeche water noted on 62-H-3 was possibly isolated to a large extent from the rest of the Gulf.

One outstanding difference between the water in the east and west Gulf is the general lessening of depth of eastern properties in the west Gulf (most noticeable below the level of seasonal influence). The major portion of the lifting of Yucatan water to form Gulf water is believed to occur along the east and northeast continental slope off Campeche Bank. The effect of lifting on the distribution of temperature, salinity, oxygen and phosphate-phosphorous can be traced in the station data proceeding westward from station 13 onto the Campeche Bank. Gulf water may be formed in any other region of the Gulf where Yucatan water flows over the shelf and slope. Areas of particular interest in this respect appear to be the southwest corner of the west Florida shelf.

Based upon the inclination of the isotherms noted, lifting along a slope could be expected to occur with a current on the slope-shelf in the opposite direction to the off slope current. We find reverse slope-shelf currents implied from data presented by Nowlin and McLellan (1967) on the southwest Florida shelf, Texas-Louisiana shelf and eastern Campeche shelf. The banded structure of the Yucatan Current first noted by Cochrane (1963, 1965) could at least partially result from lifting in the Yucatan Strait induced by the bottom configuration. The upbuilding and outbuilding processes which are characteristic of the Campeche Bank

shelf and slope may also result from carbonate precipitation (cold carbonate rich water mixing with shallower warmer water). In contrast most of the west Florida shelf was formed by upbuilding or just horizontal layering.

Water Mass Formation

Campeche Bank appears to be a pivotal area in the Gulf of Mexico. The author believes that the greatest quantity of Gulf water is formed here. The salinities greater than 36.4 per mil in the upper 75 meters at this time in the west Gulf appear to result largely from the introduction of west Campeche water.

As pointed out by Nowlin and McLellan (1967) the net flow in and out of the Gulf in the upper 1000 meters was about 30 million m^3/sec. About one-third of the inflow branches westward in the area of the northern Yucatan shelf. In order to maintain continuity, the transport in the Loop Current increases as the current flows in the southeast direction drawing mainly on the waters of the Florida shelf. The subsurface oxygen maximum in the upper 100 meters that is common in the northeast Gulf (Nowlin and McLellan, 1967) could result from the colder oxygen-rich shelf waters being drawn off the shelf along surfaces of constant density (See Appendix C).

The 250 meter sample characteristics noted in Appendix B should be compared to data from other cruises and other seasons. The characteristics of the water at this depth varies by such a large amount between the Gulf and Yucatan water that the mass adjustments associated with currents do not influence the identification significance of the observed properties. It appears that by taking a 275 meter bathythermograph lowering one should be able to distinguish if the water below was uplifted or has maintained its Yucatan characteristics. The higher the temperature at this level the more likely it is Gulf water. The more intermediate the temperature the more likely we have an admixture of both masses or limited lifting. During this cruise Yucatan water was typically warmer than 17°C and Gulf water typically colder than 15°C at the 250 meter sample.

In summary an additional factor (besides evaporation and cooling) in water mass modification in the Gulf of Mexico is lifting that apparently occurs along the continental slope and on the shelf. Yucatan water is often modified by processes acting at the surface and by slope-shelf lifting to form Gulf water. The Gulf water formed is altered at times by mixture with varying amounts of edge water and west Campeche water before passage through the Florida Straits.

Lifting is difficult to note on the straight line portions of a T-S curve but a moderation in the abruptness of inflection points can be expected. Gulf water exhibits moderated inflection points in the area of the salinity maximum and minimum when compared to Yucatan water.

CHAPTER V

CONCLUSIONS

The deep water of the Gulf of Mexico is very uniform. The source of nearly all of the water in the Gulf of Mexico is the Caribbean Sea. The water in the Gulf of Mexico is a moderated version of that in the Caribbean Sea with the temperature and salinity ranges slightly reduced at both extremes in the Gulf.

A dominant factor in the creation of new water types in the Gulf of Mexico appears to be the reduction in strength of the salinity maximum associated with the Subtropical Underwater.

Water in classes bounded by 20°C - 23.99°C and 36.2 - 36.39 per mil salinity dominates the distribution of the warm waters of the Gulf of Mexico. Water of this class is more noticeable in the western Gulf than in the eastern. It is suggested that the largest quantities of water newly formed, warmer than 16°C in the Gulf of Mexico in winter 1961-1962, falls in the above classification. Sturges (1965) reports that water in the above class does not occur in the Caribbean Sea.

This paper points to the massive lifting of water and its associated properties that occurs between the east and west Gulf. The author believes the major portion of Gulf water is formed by uplifted flow as Yucatan water passes

across the Campeche Bank. Surfaces of constant temperature, salinity, density, oxygen and phosphate-phosphorous appear at noticeably shallower depths in the western Gulf when compared to Yucatan water. The introduction of high salinity west Campeche water can be traced into the central western Gulf from the northwest corner of Campeche Bank.

The region of the Campeche Bank appears to be a focal point for water mass formation, modification and distribution in the Gulf of Mexico. A comprehensive study of the oceanography of Campeche Bank could produce very enlightening results.

The author believes that synoptic cruises covering the entire Gulf should be undertaken as often as possible. Since conditions in the Gulf are very variable it appears that water mass formation and tracing in the Gulf can most easily be accomplished from data collected on such cruises. Study of Gulf water using combined data from different years, even though they may represent observations from the same season, is often very difficult, if not impossible.

CHAPTER VI

RECOMMENDATIONS FOR FUTURE STUDY

The following areas appear attractive to future study:

(A) The oxygen and phosphate distribution in the region of the Yucatan Strait and its relation to the current structure and bottom configuration.

(B) A detailed study of the currents and water mass properties in the Campeche Bank region.

(C) The geology of Campeche Bank should be investigated in more detail. The pattern of upbuilding and outbuilding of Campeche Bank should also be seen on the southwest corner of the west Florida shelf.

(D) The lifting associated with flow over the Campeche Bank should make the nutrient rich currents off that bank good indicators as to the location of biomass.

(E) A closer investigation of the apparent shelf/slope lifting and the shelf countercurrent.

(F) Since the water in the Gulf below the sill depth is nearly homogeneous in respect to temperature, salinity and density, other properties (ie. oxygen or phosphate-phosphorous) should be investigated as clues to the motion and renewal of these waters.

(G) The changes in the characteristic T-S and O_2-T curves should be studied before and after hurricane passage. The effect of a hurricane on the Gulf could be

studied and if changes occur it would be interesting to see how long they persist.

(H) It is recommended that a similar synoptic survey of the Gulf of Mexico be undertaken in other seasons in order to recognize the seasonal influence on the water types of the Gulf.

(I) By using Nansen bottles the precise extreme values of properties (especially salinity) of a water column are often missed. The STD offers an obvious solution to this problem with its continuous trace of temperature and salinity with depth.

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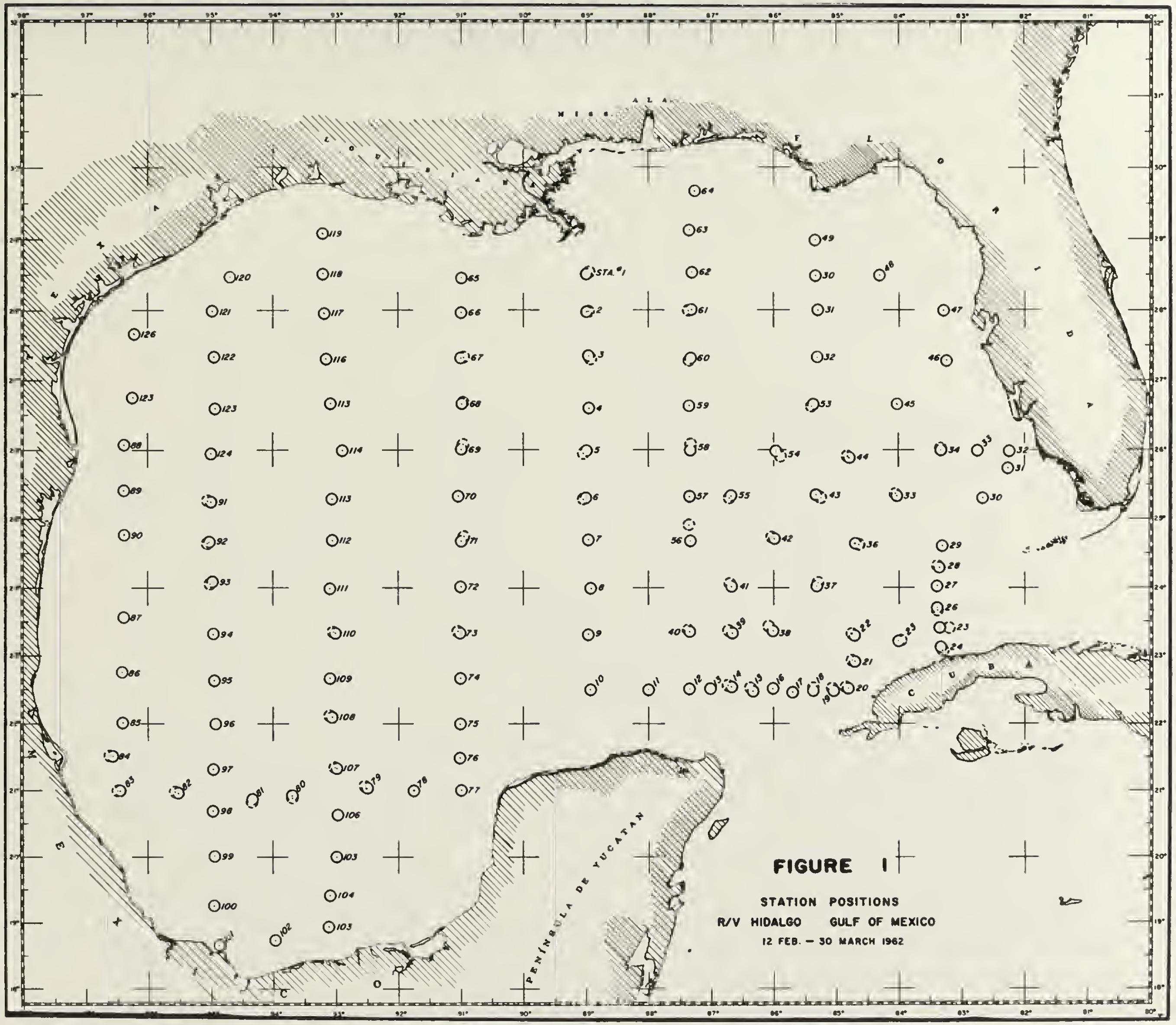


FIGURE 1

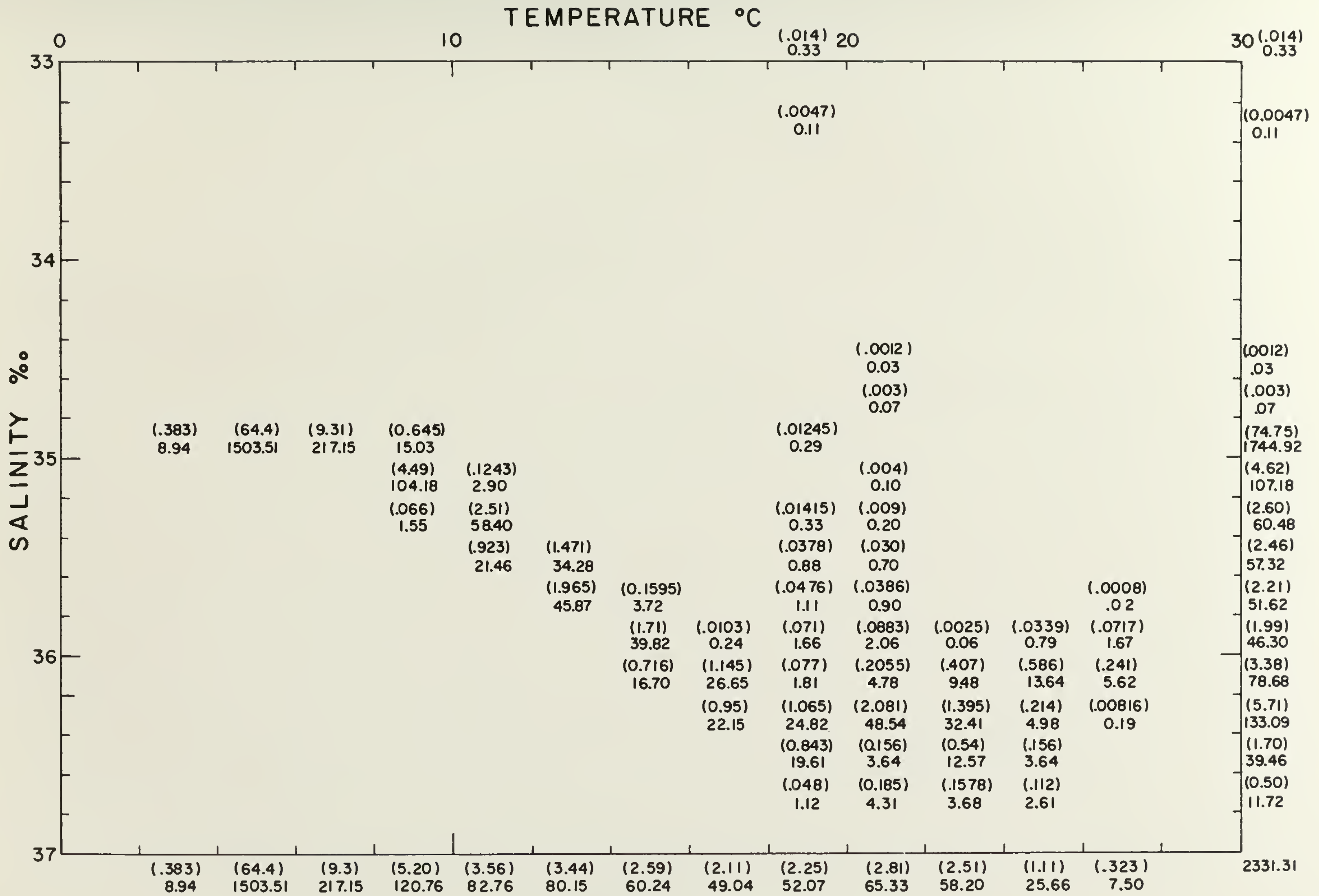
STATION POSITIONS

R/V HIDALGO GULF OF MEXICO

12 FEB. — 30 MARCH 1962

FIGURE 2.

GULF OF MEXICO ON A COARSE SCALE DIAGRAM OF POTENTIAL TEMPERATURE VS. SALINITY. Numbers in the body of the diagram when multiplied by 1000 Km^3, represent the volume of water in each class 2°C x 0.2 per mil. Sums at bottom give the distribution by potential temperature and at the right by salinity. Numbers in parenthesis indicate percentage of total. Numbers in upper margin represent salinities less than 33 per mil.



TEMPERATURE °C
0
10
20
30
SALINITY ‰
33
34
35
36
37
(.014) 0.33
(.0047) 0.11
(.0012) 0.03
(.003) 0.07
(.383) 8.94
(64.4) 1503.51
(9.31) 217.15
(0.645) 15.03
(.01245) 0.29
(4.49) 104.18
(.1243) 2.90
(.004) 0.10
(.066) 1.55
(2.51) 58.40
(.01415) 0.33
(.009) 0.20
(.923) 21.46
(1.471) 34.28
(.0378) 0.88
(.030) 0.70
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(0.1595) 3.72
(.0476) 1.11
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(1.71) 39.82
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(.071) 1.66
(.0883) 2.06
(.0025) 0.06
(.0339) 0.79
(.0717) 1.67
(0.716) 16.70
(1.145) 26.65
(.077) 1.81
(.2055) 4.78
(.407) 9.48
(.586) 13.64
(.241) 5.62
(0.95) 22.15
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(2.081) 48.54
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(.214) 4.98
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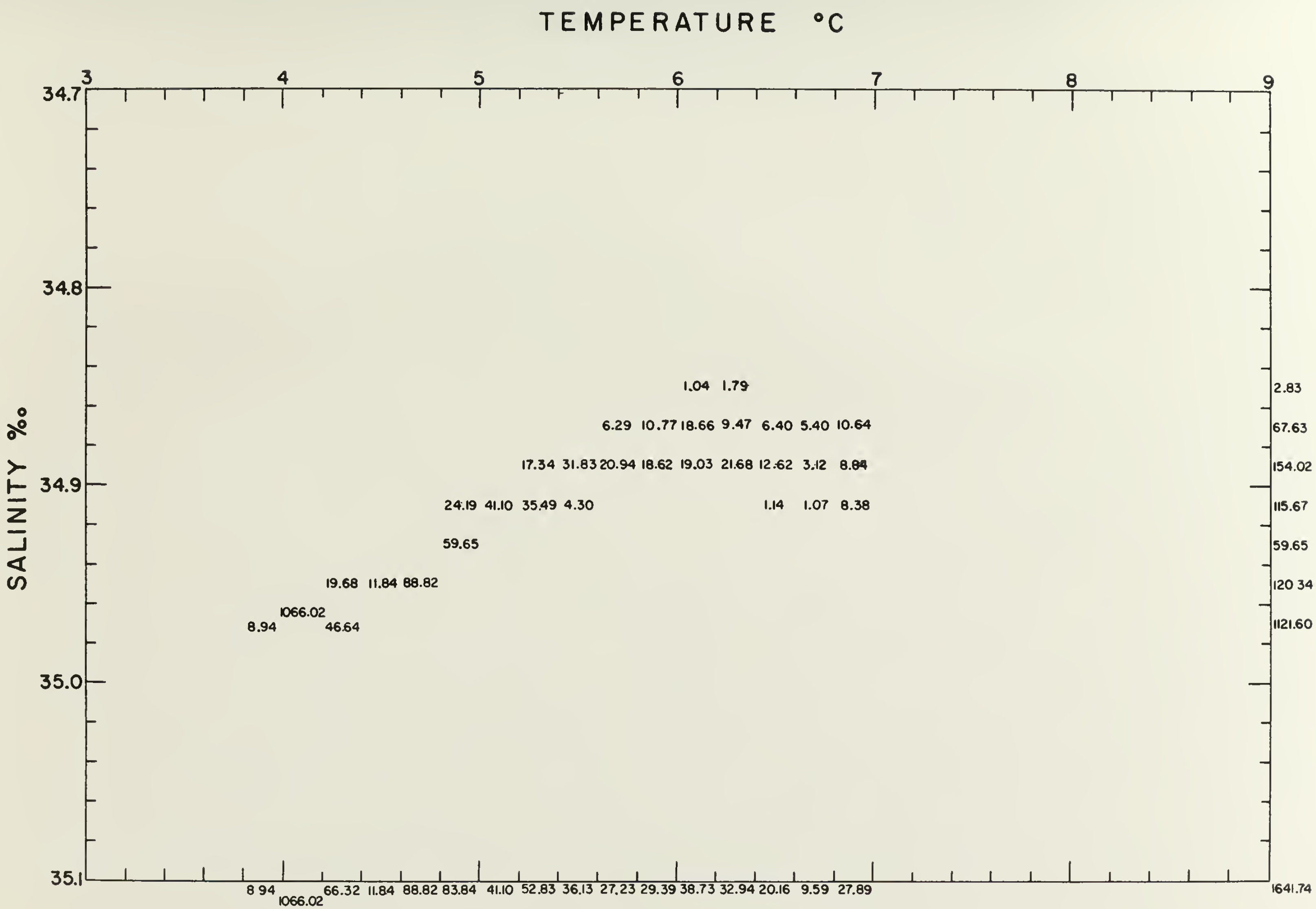
(3.56) 82.76
(3.44) 80.15
(2.59) 60.24
(2.11) 49.04
(2.25) 52.07
(2.81) 65.33
(2.51) 58.20
(1.11) 25.66
(.323) 7.50
2331.31

FIGURE 2

FIGURE 3.

DEEP WATERS (WATER COLDER THAN 7°C) OF THE GULF OF MEXICO ON A FINE SCALE DIAGRAM OF POTENTIAL TEMPERATURE VS. SALINITY. Numbers in the body of the diagram, when multiplied by 1000 Km^3, represents the volume of water in each class 0.2°C x 0.02 per mil. Sums at bottom give the distribution by potential temperature and at the right by salinity.



TEMPERATURE °C
3
4
5
6
7
8
9
34.7
34.8
34.9
35.0
35.1
SALINITY ‰
1.04 1.79
6.29 10.77 18.66 9.47 6.40 5.40 10.64
17.34 31.83 20.94 18.62 19.03 21.68 12.62 3.12 8.84
24.19 41.10 35.49 4.30 1.14 1.07 8.38
59.65
19.68 11.84 88.82
1066.02
8.94 46.64
2.83
67.63
154.02
115.67
59.65
120 34
1121.60
1641.74
8 94 1066.02 66.32 11.84 88.82 83.84 41.10 52.83 36.13 27.23 29.39 38.73 32.94 20.16 9.59 27.89

FIGURE 3

FIGURE 4.

EASTERN GULF OF MEXICO (EAST OF 90°W) ON A COARSE SCALE DIAGRAM OF POTENTIAL TEMPERATURE VS. SALINITY. Numbers in the body of the diagram when multiplied by 1000 Km^3 represent the volume of water in each class 2°C x 0.2 per mil. Sums at the bottom give the distribution by potential temperature and at the right by salinity.

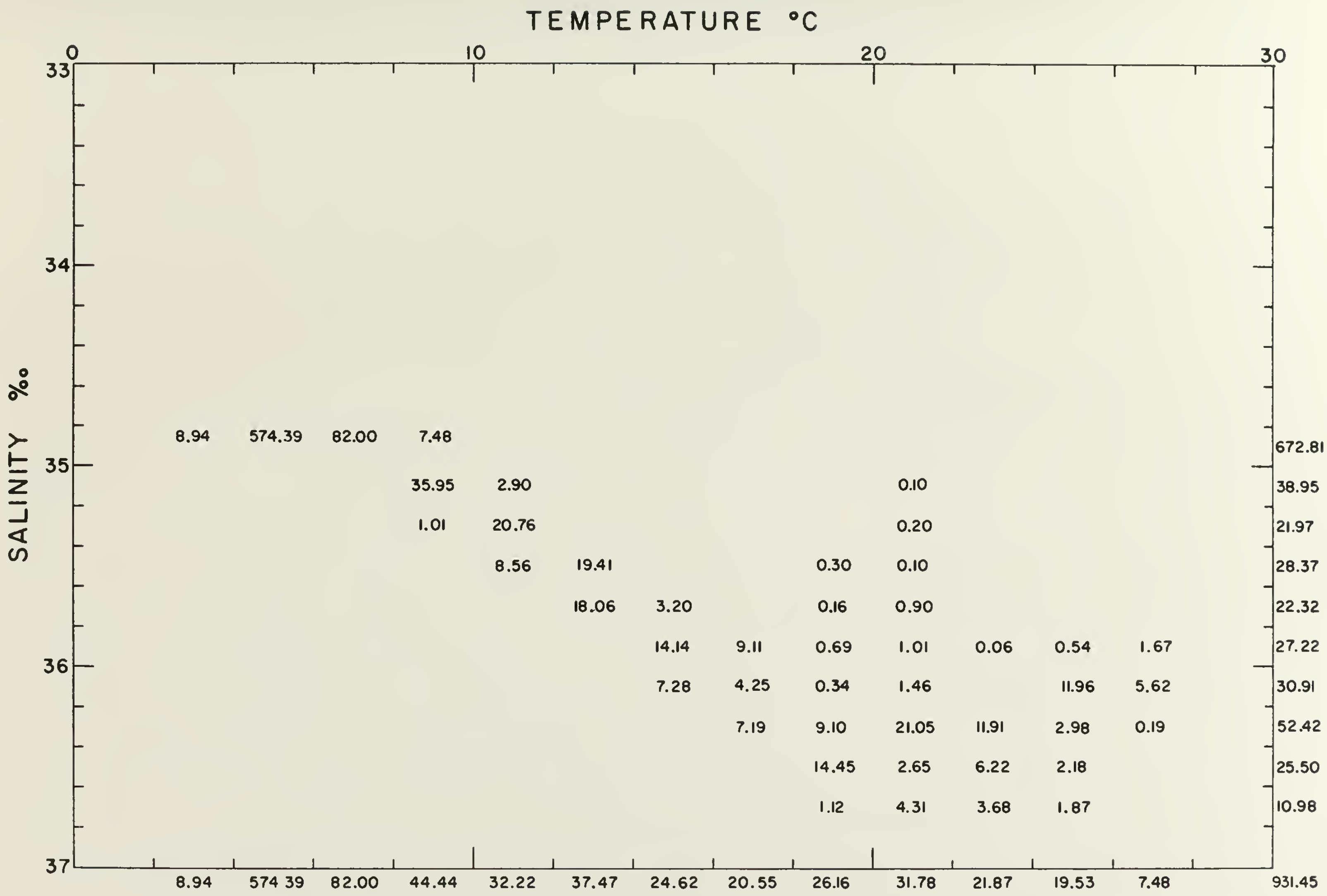

TEMPERATURE °C
0
10
20
30
SALINITY ‰
33
34
35
36
37
8.94 574.39 82.00 7.48
35.95 2.90 0.10
1.01 20.76 0.20
8.56 19.41 0.30 0.10
18.06 3.20 0.16 0.90
14.14 9.11 0.69 1.01 0.06 0.54 1.67
7.28 4.25 0.34 1.46 11.96 5.62
7.19 9.10 21.05 11.91 2.98 0.19
14.45 2.65 6.22 2.18
1.12 4.31 3.68 1.87
672.81
38.95
21.97
28.37
22.32
27.22
30.91
52.42
25.50
10.98
8.94 574 39 82.00 44.44 32.22 37.47 24.62 20.55 26.16 31.78 21.87 19.53 7.48 931.45

FIGURE 4

FIGURE 5.

WESTERN GULF OF MEXICO (WEST OF 90°W) ON A COARSE SCALE DIAGRAM OF POTENTIAL TEMPERATURE VS. SALINITY. Numbers in the body of the diagram, when multiplied by 1000 Km^3 represent the volume of water in each class 2°C x 0.2 per mil. Sums at the bottom give the distribution by potential temperature and at the right by salinity. Numbers in the upper margin represent water with a salinity of less than 33 per mil.

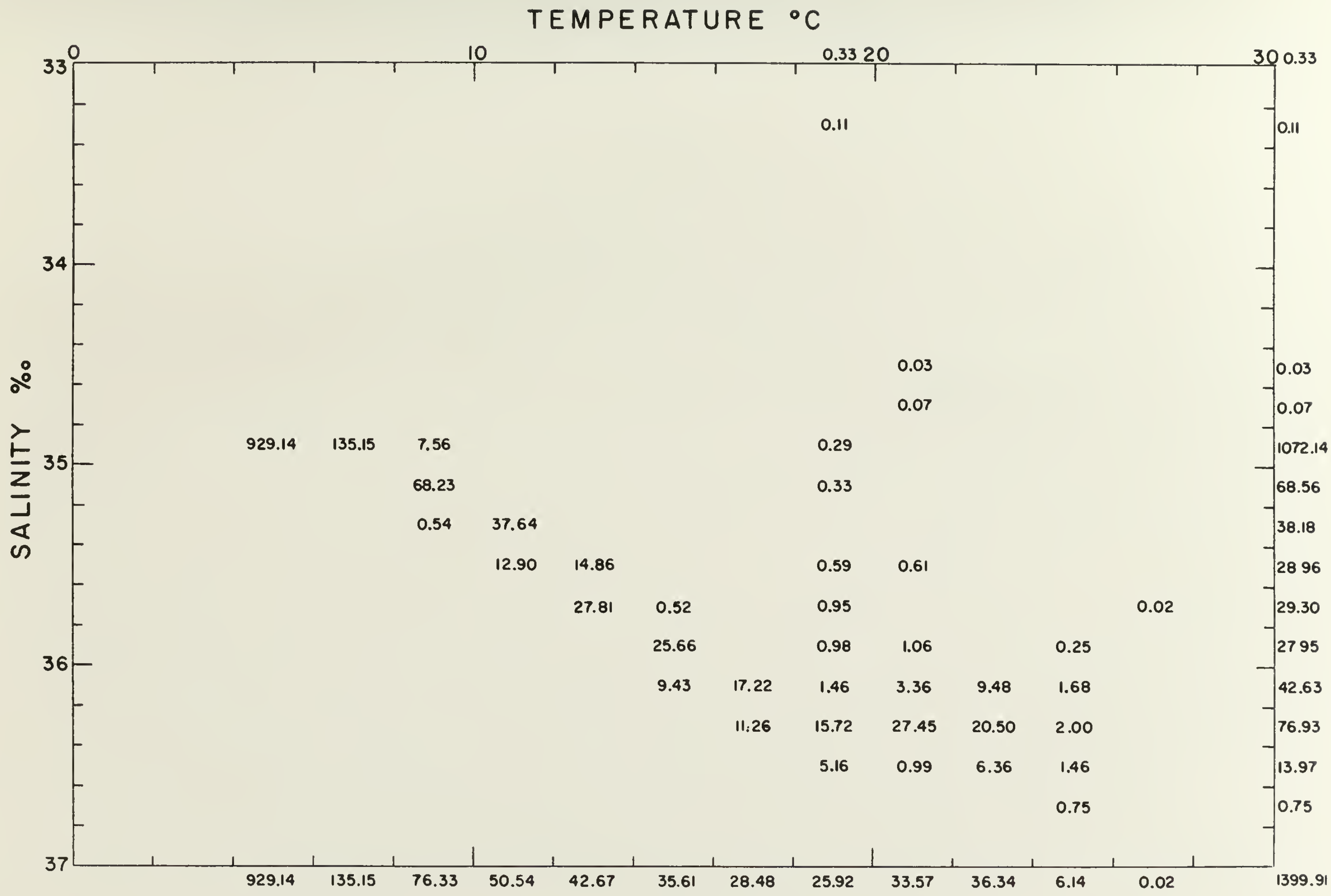

TEMPERATURE °C
SALINITY ‰
0
10
20
30
33
34
35
36
37
0.33
0.11
0.03
0.07
1072.14
68.56
38.18
28 96
29.30
27 95
42.63
76.93
13.97
0.75
1399.91
929.14 135.15 7.56 0.29
68.23 0.33
0.54 37.64
12.90 14.86 0.59 0.61
27.81 0.52 0.95 0.02
25.66 0.98 1.06 0.25
9.43 17.22 1.46 3.36 9.48 1.68
11.26 15.72 27.45 20.50 2.00
5.16 0.99 6.36 1.46
0.75
929.14 135.15 76.33 50.54 42.67 35.61 28.48 25.92 33.57 36.34 6.14 0.02

FIGURE 5

FIGURE 6.

CHANGE IN PER CENT BETWEEN THE WEST AND EAST PORTIONS (DIVISION AT 90°W) OF THE GULF OF MEXICO OF WATER ABOVE 16°C ON COARSE SCALE DIAGRAM. Numbers in the body of the figure represent percentage differences (west - east) in each class 2°C x 0.2 per mil. Numbers appearing in the upper margin represent water with a salinity less than 33 per mil.

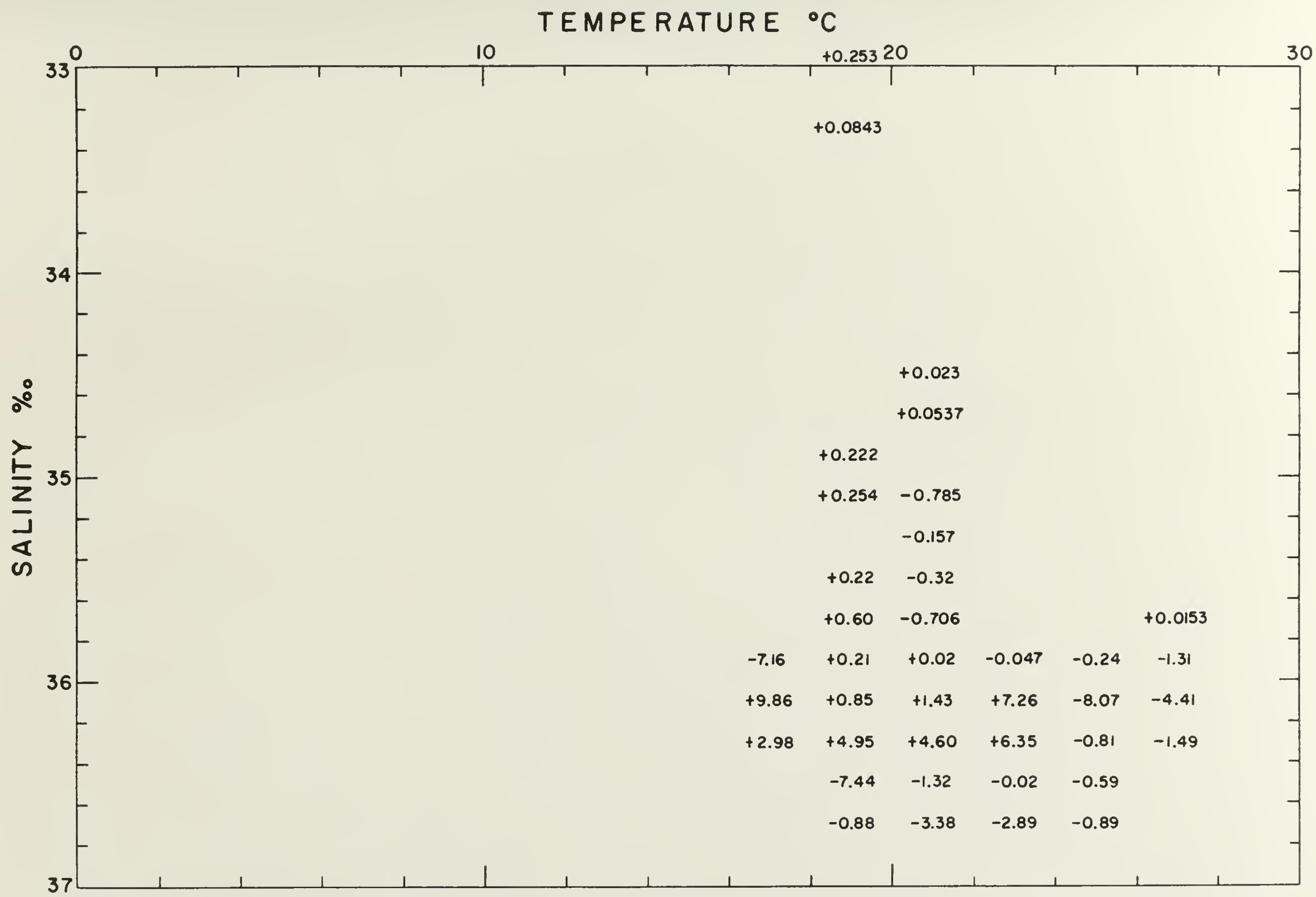

TEMPERATURE °C
SALINITY ‰
0
10
20
30
33
34
35
36
37
+0.253
+0.0843
+0.023
+0.0537
+0.222
+0.254
-0.785
-0.157
+0.22
-0.32
+0.60
-0.706
+0.0153
-7.16
+0.21
+0.02
-0.047
-0.24
-1.31
+9.86
+0.85
+1.43
+7.26
-8.07
-4.41
+2.98
+4.95
+4.60
+6.35
-0.81
-1.49
-7.44
-1.32
-0.02
-0.59
-0.88
-3.38
-2.89
-0.89

FIGURE 6

FIGURE 7.

CHANGE IN PER CENT BETWEEN GULF OF MEXICO AND CARIBBEAN SEA OF WATER ABOVE 16°C ON A COARSE SCALE DIAGRAM. Numbers in the body of the figure represent percentage differences (Gulf-Caribbean) in each class 2°C x 0.2 per mil. Numbers appearing in the upper margin represent water with a salinity less than 33 per mil.

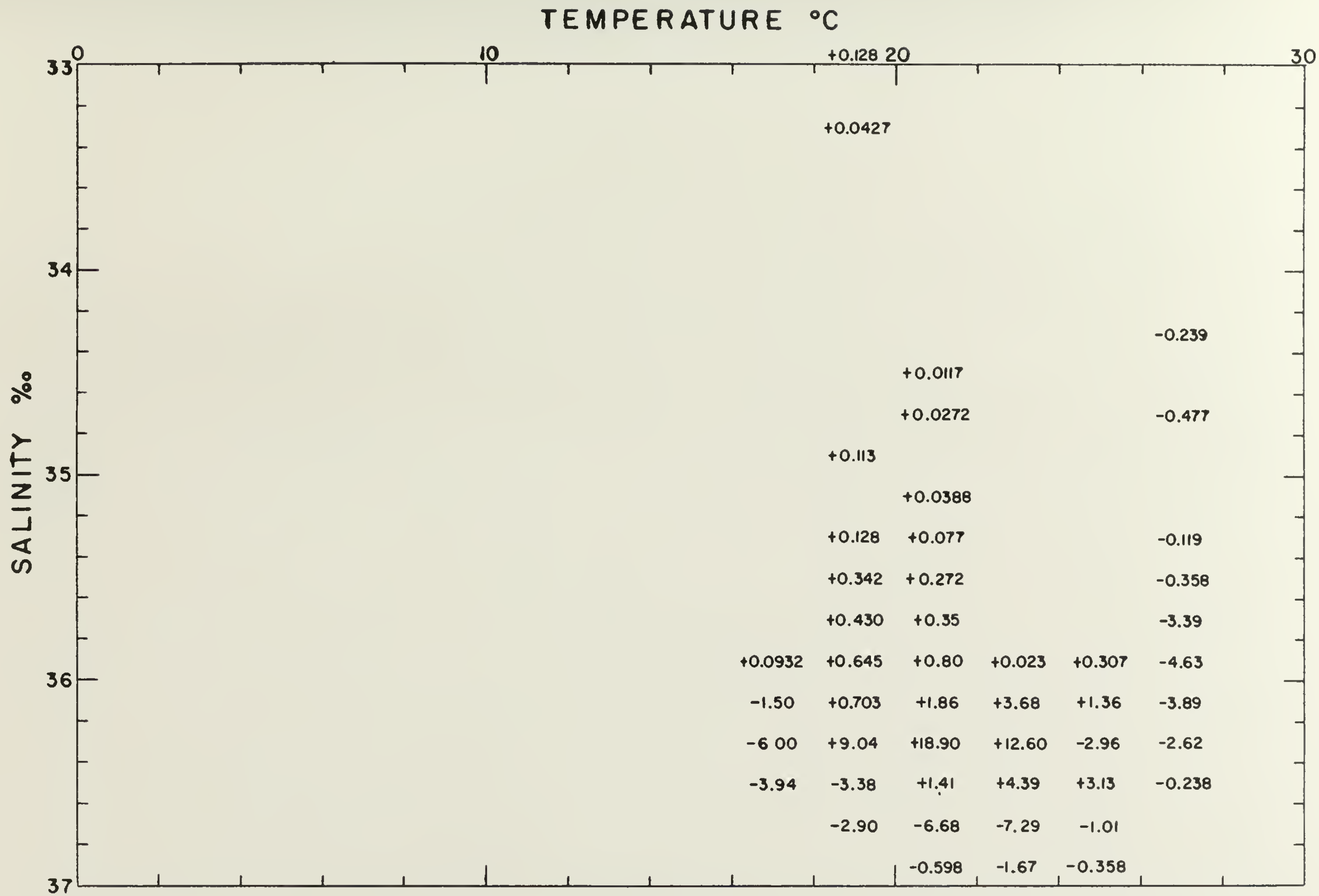

TEMPERATURE °C
0
10
+0.128 20
30
SALINITY ‰
33
34
35
36
37
+0.0427
-0.239
+0.0117
+0.0272
-0.477
+0.113
+0.0388
+0.128
+0.077
-0.119
+0.342
+ 0.272
-0.358
+0.430
+0.35
-3.39
+0.0932
+0.645
+0.80
+0.023
+0.307
-4.63
-1.50
+0.703
+1.86
+3.68
+1.36
-3.89
-6 00
+9.04
+18.90
+12.60
-2.96
-2.62
-3.94
-3.38
+1.41
+4.39
+3.13
-0.238
-2.90
-6.68
-7.29
-1.01
-0.598
-1.67
-0.358

FIGURE 7

FIGURE 8.

CHANGE IN PER CENT BETWEEN THE GULF OF MEXICO AND THE CARIBBEAN SEA ON A COARSE SCALE DIAGRAM. Numbers in the body of the figure represent differences (Gulf-Caribbean) in each class 2°C x 0.2 per mil.

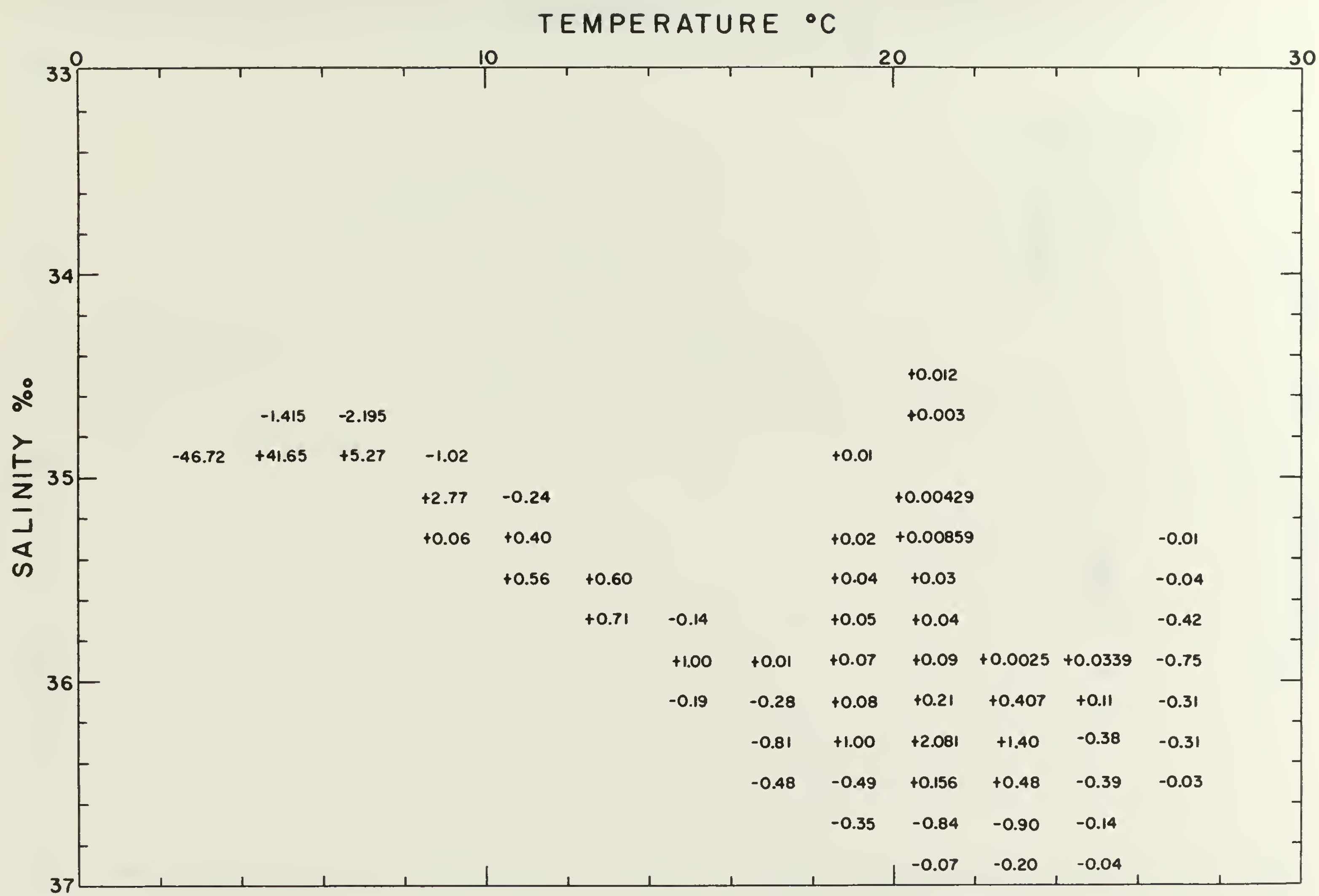

TEMPERATURE °C
0
10
20
30
SALINITY ‰
33
34
35
36
37
+0.012
-1.415 -2.195 +0.003
-46.72 +41.65 +5.27 -1.02 +0.01
+2.77 -0.24 +0.00429
+0.06 +0.40 +0.02 +0.00859 -0.01
+0.56 +0.60 +0.04 +0.03 -0.04
+0.71 -0.14 +0.05 +0.04 -0.42
+1.00 +0.01 +0.07 +0.09 +0.0025 +0.0339 -0.75
-0.19 -0.28 +0.08 +0.21 +0.407 +0.11 -0.31
-0.81 +1.00 +2.081 +1.40 -0.38 -0.31
-0.48 -0.49 +0.156 +0.48 -0.39 -0.03
-0.35 -0.84 -0.90 -0.14
-0.07 -0.20 -0.04

FIGURE 8

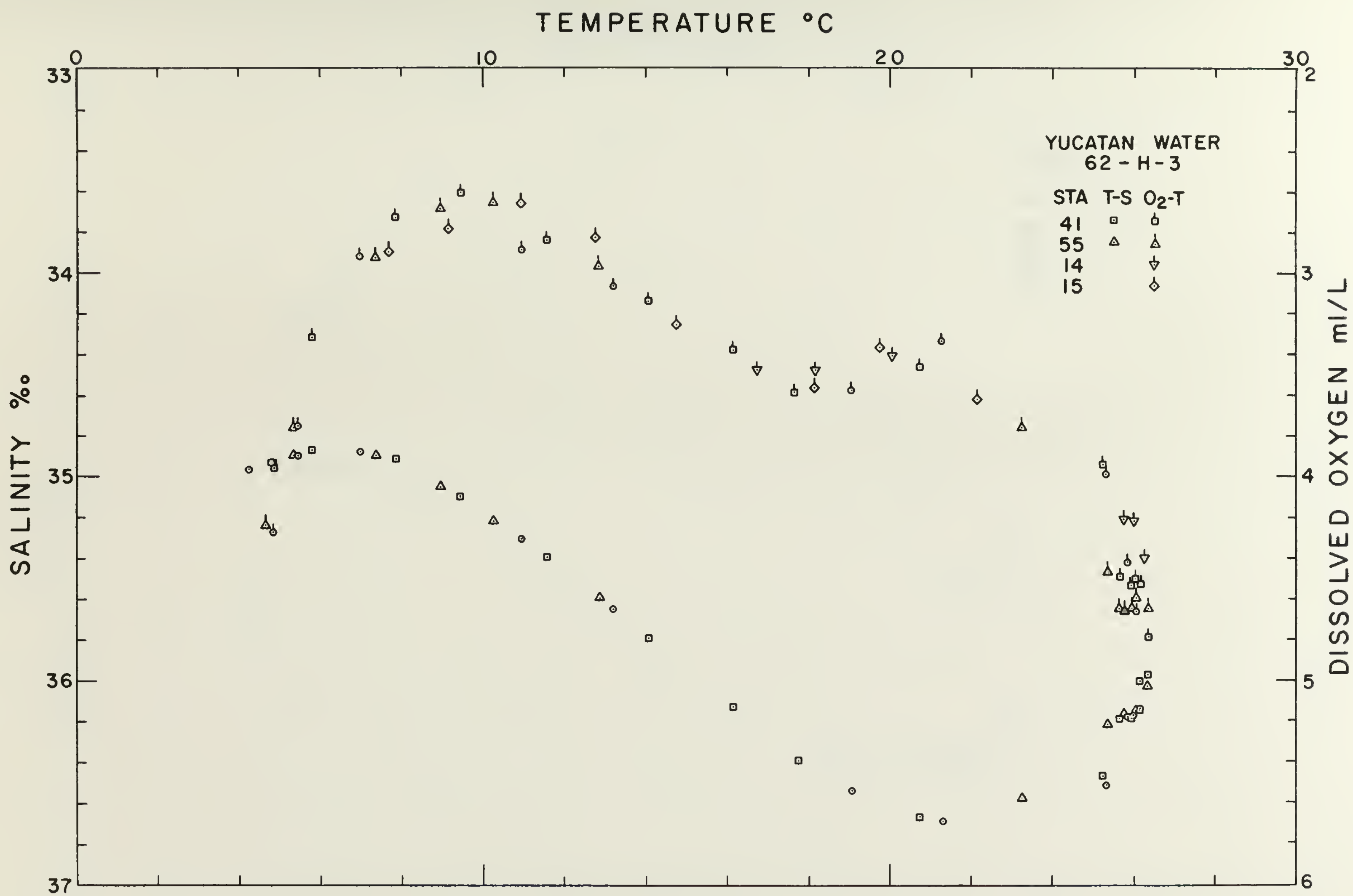
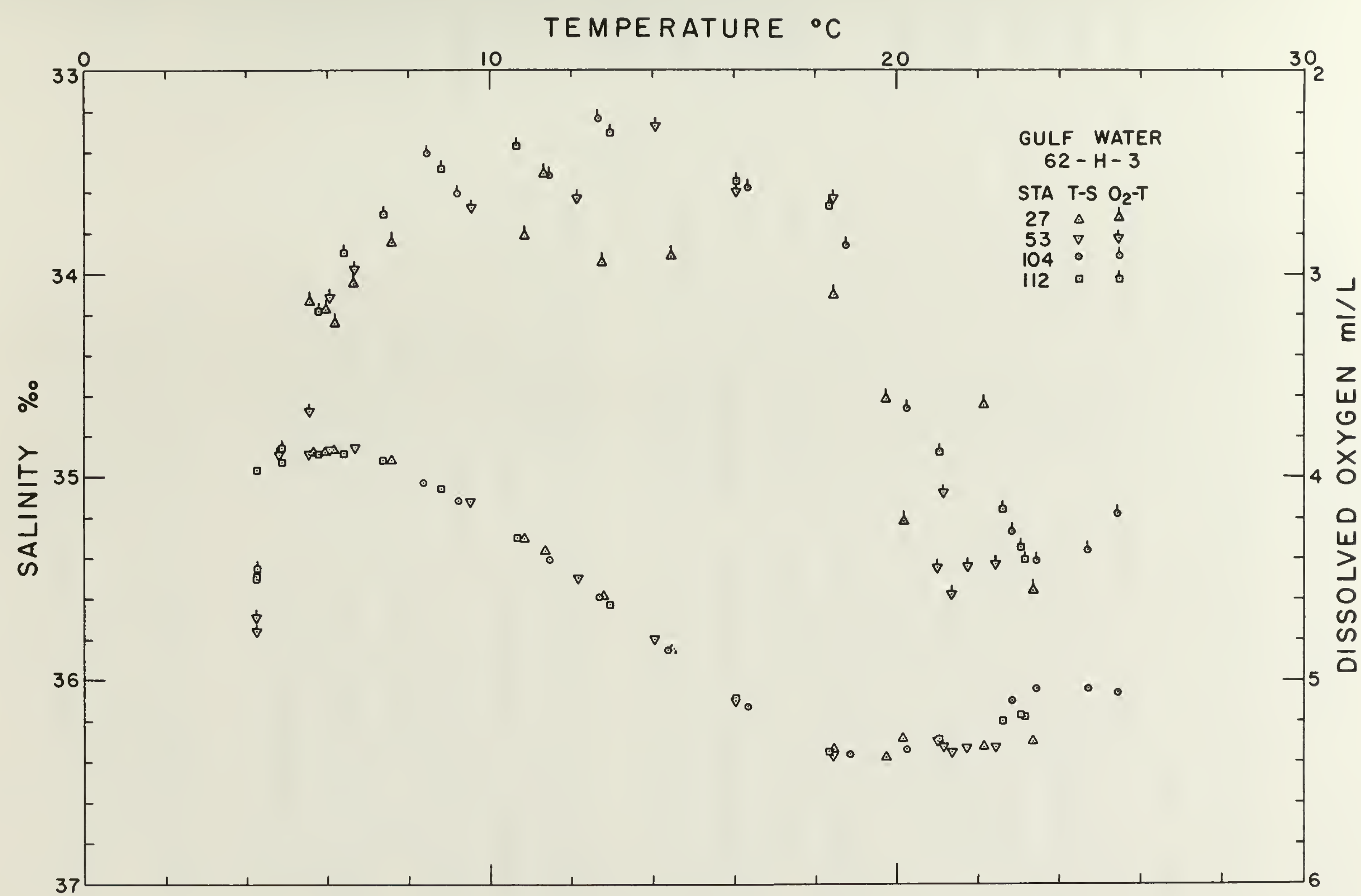

TEMPERATURE °C
0
10
20
30
33
34
35
36
37
SALINITY ‰
2
3
4
5
6
DISSOLVED OXYGEN ml/L
YUCATAN WATER
62 - H - 3
STA T-S O_2-T
41
55
14
15

FIGURE 9



TEMPERATURE °C
0
10
20
30
33
34
35
36
37
2
3
4
5
6
SALINITY ‰
DISSOLVED OXYGEN ml/L
GULF WATER
62 - H - 3
STA T-S O_2-T
27
53
104
112

FIGURE 10

APPENDIX A

Detailed Description of Method

The main objective of my method was to estimate the volumes of the different water classes in the Gulf using the basic method initiated by Cochrane (1958), Pollak (1958) and Montgomery (1958). The Gulf was segmented into units of one degree squares of longitude and latitude. A station or group of stations were chosen which best described the water in a given one degree square.

Only observed data as published by McLellan and Nowlin (1962) was used. This amounts to approximately 1590 sampling points. Each *in situ* temperature was converted to potential temperature using the results of Helland-Hansen (1930).

Each sample was weighted in proportion to the thickness of the layer it was assumed to represent in the one degree area. The layer thickness was determined by the midpoints between samples or by the boundaries. The largest volume assigned to a particular sample was 24,670 Km^3 with about 75 per cent of the samples representing less than 1000 Km^3.

The average depth of each one degree square of the Gulf of Mexico was obtained by graphical integration. One hundred equally spaced soundings were averaged for each one degree square of Gulf of Mexico surface. Next a single

hydrographic station or group of stations was assigned to represent each one degree square. The selection of a station to represent a given one degree square was based on the position and maximum sampling depth of the station. An effort was made to use all 126 stations and thus to maximize the number of sampling points. Cruise 62-H-3 stations formed a grid which particularly lent itself to the method described above. The maximum surface area assigned to any one sample was equal to slightly more than 45,000 Km^2 or about four one degree squares. The largest areas were assigned to deep samples.

Where a one degree square having a great average depth was represented by two stations, one deep and one shallow, the surface area was divided equally between both stations for the samples in the upper layers but the entire surface area was assigned to the deep samples from the deeper station. A similar procedure was followed when more than two stations represented a unit one degree square.

Hydrographic charts 2056, 1126, BC0905N were used for graphical integration. One degree square areas were obtained from HO 614. For the purpose of this paper the Gulf of Mexico is divided into east and west portions separated at the 90°W meridian.

The volume of the entire Gulf of Mexico was found to be 2331.31 x 10^3 Km^3 which compares favorably with published

figures (Hunt and Groves, 1965). It is emphasized that only observed values of temperature and salinity were used in order not to introduce the inaccuracies associated with interpolation. The area of the Gulf used was 1543 x 10^3 Km^2.

In order to facilitate the summation of water types, the following information for each sample was placed on a file card: potential temperature, salinity, layer thickness, surface area and volume of water represented by the sample.

The selection of boundaries for each bivariate class of potential temperature and salinity parallels those chosen by Sturges (1965) in order to facilitate comparison of results. The two scales thus chosen were 2°C x 0.2 per mil (coarse) and 0.2°C x 0.02 per mil (fine). All presentations are made in the coarse scale with the exception of the fine scale diagram for water colder than 7°C. The fine scale presentation was made in order to closely examine the water in the region of the salinity minimum. Over seventy per cent of the water in the Gulf of Mexico is colder than 7°C.

APPENDIX B

Observations at Sampling Depth Closest to 250 Meters

for Stations on Cruise 62-H-3

Station	Depth (M)	Temperature (°C)	Salinity (°/oo)	Sigma-T (g/1)	Oxygen (ml/1)	Phosphate (ug.-at./1)
1	248	13.36	35.695	26.88	2.78	1.09
2	250	14.00	35.791	26.82	2.85	0.92
3	250	14.17	35.812	26.80	2.92	0.92
4	250	16.90	36.228	26.50	3.14	0.61
5	257	15.71	36.044	26.63	2.88	0.61
6	249	14.04	35.791	26.81	2.61	1.08
7	250	13.76	35.746	26.83	2.73	1.28
8	250	13.40	35.696	26.87	2.54	1.30
(Y)14	232	16.75	36.213	26.52	3.48	0.57
(Y)15	200	18.14	36.452	26.37	3.57	0.40
(Y)16	232	18.83	36.517	26.24	3.41	0.31
(Y)17	266	18.76	36.500	26.25	3.64	0.30
(Y)18	249	19.06	36.542	26.20	3.58	0.36

(Y) next to station number designates Yucatan water.
(?) after a number indicates a questioned value.

APPENDIX B (Continued)

Station	Depth (M)	Temperature (°C)	Salinity (°/oo)	Sigma-T (g/1)	Oxygen (ml/1)	Phosphate (ug.-at./1)
(Y)19	242	19.65	36.595	26.09	3.03	0.31
(Y)20	241	19.66	36.600	26.09	3.45	0.35
(Y)21	244	19.94	36.623	26.03	3.24	0.35
(Y)22	250	19.35	36.570	26.15	3.53	0.39
(Y)23	250	19.09	36.541	26.19	3.38	0.35
(Y)24	245	18.99	36.525	26.21	3.49	0.30
25	247	15.83	36.069	26.63	3.02	0.53
26	293	9.63	35.146	27.15	2.72	1.66
27	250	11.32	35.369	27.02	2.51	1.37
28	273	10.95	35.316	27.05	2.65	1.48
(Y)36	200	19.90	36.523	25.97	3.49	0.35
(Y)37	299	18.06	36.425	26.37	3.63	0.45
(Y)38	237	19.49	36.578	26.12	3.44	0.40
(Y)39	226	19.21	36.574	26.19	2.70(?)	0.42
(Y)41	200	20.71	36.674	25.87	3.47	0.38
(Y)42	243	19.69	36.598	26.08	3.42	0.50

(Y) next to station number designates Yucatan water.
(?) after a number indicates a questioned value.

APPENDIX B (Continued)

Station	Depth (M)	Temperature (°C)	Salinity ($^{o}/oo$)	Sigma-T (g/1)	Oxygen (ml/1)	Phosphate (ug.-at./1)
43	250	15.08	35.950	26.70	2.93	1.16
44	248	11.77	35.438	26.99	2.64	1.59
51	250	12.93	35.620	26.91	2.91	1.57
52	250	13.79	35.747	26.83	2.70	1.20
53	250	14.06	35.797	26.81	2.28	1.16
(Y)54	259	16.52	36.189	26.56	3.31	0.68
(Y)55	250	---	---	---	3.49	0.04(?)
(Y)56	255	17.30	36.319	26.47	3.64	0.51
(Y)57	269	16.88	36.246	26.52	3.40	0.63
(Y)58	250	15.62	36.041	26.65	3.36	0.77
59	244	13.98	35.780	26.81	2.82	1.10
60	247	15.57	36.027	26.65	2.97	0.70
61	231	14.69	35.890	26.74	2.87	0.98
62	246	14.26	35.825	26.79	2.69	1.09
63	250	11.88	35.460	26.99	2.55	1.39
67	250	12.35	35.532	26.95	2.76	1.36

(Y) next to station number designates Yucatan water.
(?) after a number indicates a questioned value.

APPENDIX B (Continued)

Station	Depth (M)	Temperature (°C)	Salinity ($^{o}/oo$)	Sigma-T (g/1)	Oxygen (ml/1)	Phosphate (ug.-at./1)
68	250	14.23	35.824	26.79	2.74	1.23
69	269	14.27	35.830	26.79	2.71	1.12
70	250	15.74	36.046	26.63	2.73	0.84
71	239	16.19	36.117	26.58	2.84	0.72
72	250	14.90	35.926	26.73	2.47	0.88
73	244	13.78	35.774	26.85	2.67	---
74	250	13.48	35.706	26.86	2.61	1.23
79	249	13.22	35.674	26.89	2.52	1.39
80	244	13.88	35.770	26.82	2.59	1.12
81	246	12.38	35.550	26.96	2.41	1.52
82	240	13.64	35.733	26.85	2.56	1.61
83	265	12.18	35.514	26.97	2.47	1.57
84	247	13.74	35.746	26.84	2.59	1.38
85	250	13.72	35.746	26.84	2.52	0.99
86	244	14.26	35.853	26.81	0.61	1.25
87	249	15.01	35.945	26.72	2.65	1.10

(Y) next to station number designates Yucatan water.
(?) after a number indicates a questioned value.

APPENDIX B (Continued)

Station	Depth (M)	Temperature (°C)	Salinity ($^{o}/oo$)	Sigma-T (g/1)	Oxygen (ml/1)	Phosphate (ug.-at./1)
89	243	13.25	35.677	26.88	2.85	1.30
90	250	12.47	35.563	26.95	2.54	1.54
91	256	13.92	35.775	26.82	2.68	1.10
92	248	11.30	35.388	27.04	2.51	1.55
93	247	14.50	35.882	26.78	2.67	1.10
94	250	15.17	35.963	26.69	2.52	0.93
95	229	15.10	35.954	26.70	2.56	1.12
96	237	14.78	35.903	26.73	2.30	0.96
97	248	13.92	35.770	26.82	2.32	1.22
98	232	14.10	35.801	26.80	2.49	1.26
99	245	12.25	35.528	26.97	2.18	1.42
100	250	12.83	35.609	26.92	2.22	1.47
104	250	12.68	35.586	26.93	2.24	1.57
105	245	12.92	35.629	26.91	2.28	1.47
106	248	13.14	35.652	26.89	2.50	1.16
107	250	13.45	35.704	26.86	2.43	1.40

(Y) next to station number designates Yucatan water.
(?) after a number indicates a questioned value.

APPENDIX B (Continued)

Station	Depth (M)	Temperature (°C)	Salinity ($^{o}/oo$)	Sigma-T (g/l)	Oxygen (ml/l)	Phosphate (ug.-at./l)
108	250	12.80	35.608	26.92	2.37	1.53
109	250	14.48	35.858	26.76	2.72	1.27
110	250	14.71	35.895	26.74	2.30	1.30
111	250	14.61	35.879	26.75	2.56	1.33
112	293	12.92	35.626	26.91	2.31	1.45
113	235	14.03	35.796	26.81	3.02	1.27
114	245	9.97	35.202	27.13	2.49	1.85
115	267	11.45	35.400	27.02	2.30	1.66
116	250	11.33	35.376	27.03	2.43	1.78
122	250	12.15	35.506	26.97	2.41	1.64
123	258	13.78	35.750	26.83	2.60	1.39
124	250	13.87	35.761	26.82	2.54	1.31
125	250	13.02	35.636	26.90	2.41	1.52

(Y) next to station number designates Yucatan water.

(?) after a number indicates a questioned value.

APPENDIX C

Observations Associated with Subsurface Oxygen Maximum in Depths Less Than 100 Meters at Selected Stations in the Northeast Gulf of Mexico During Cruise 62-H-3

Station	Depth (M)	Temperature (°C)	Salinity ($^{o}/oo$)	Oxygen (ml/l)	Sigma-T (g/l)
43	50	23.70	36.265	4.75	24.71
44	25	22.28	*36.280	4.67	25.13
45	20	21.20	36.067	5.02	25.27
45	75	18.51	36.316	5.02	26.17
46	20	18.42	*35.893	5.18	25.87
47	15	18.86	*35.807	5.31	25.69
48	20	17.63	35.992	5.19	26.14
48	35	16.99	36.078	5.39	26.36
49	20	18.77	35.546	5.15	25.52
50	10	20.71	35.550	4.79	25.01
51	25	21.25	*36.108	4.87	25.29
51	75	20.80	*36.376	4.53	25.61
52	10	22.25	*36.323	4.70	25.17
52	75	21.06	36.316	4.68	25.50
53	50	21.39	*36.348	4.58	25.43

* indicates salinity inflection point.